Construction of a New Isotope Production Facility

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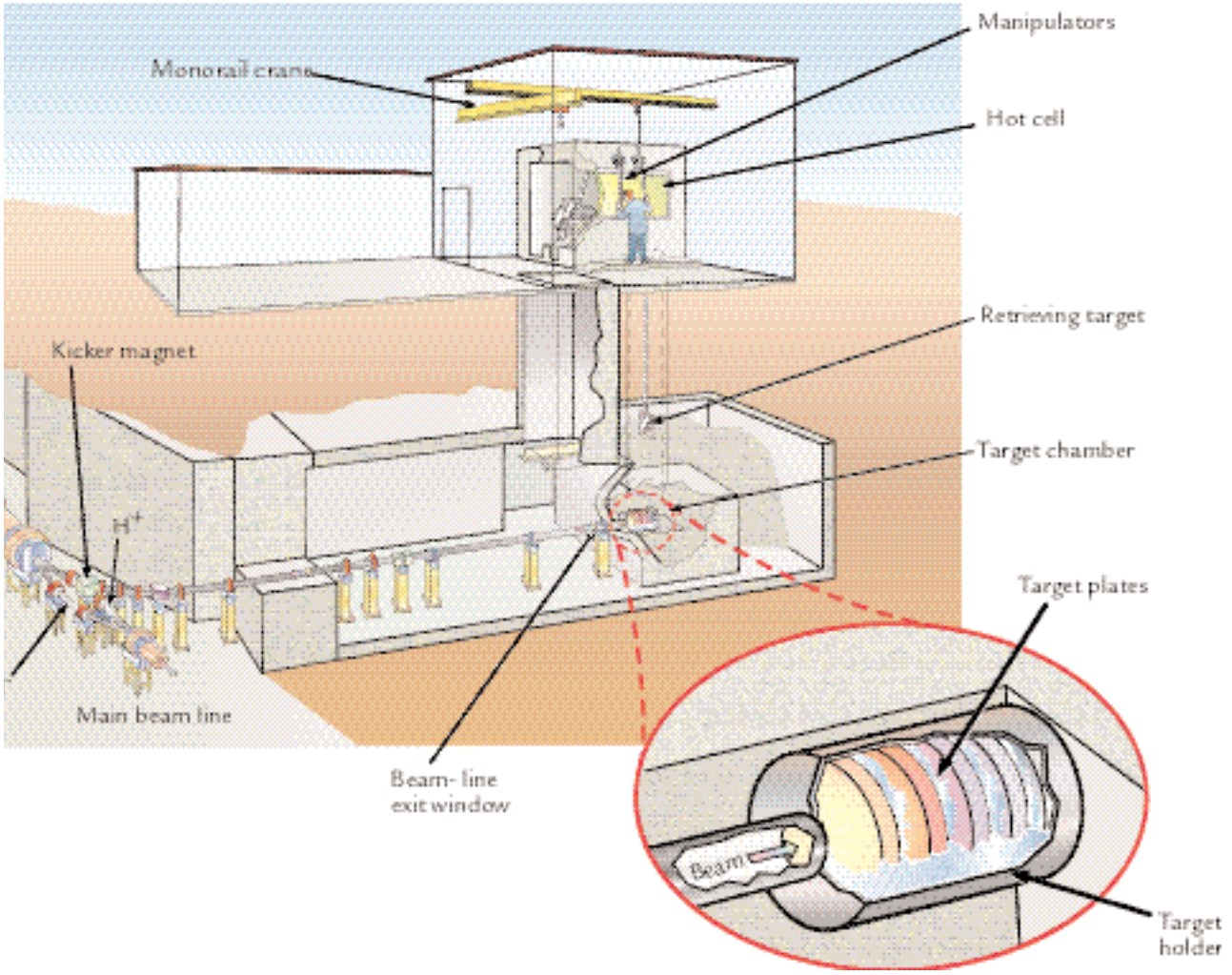
Radioisotopes, the unstable isotopes of chemical elements, dissipate excess energy by spontaneously emitting radiation in the form of alpha, beta, and gamma rays. This release of energy by radioactive decay makes radioisotopes a useful tool in medicine and research. Radioisotopes introduced into the body are taken up in different amounts by different organs and can be used for diagnosis and treatment of disease. Recording the distribution and concentrations of radionuclides as they decay provides clinicians with information about the presence, size, and shape of various abnormalities in body organs. Iodine-131, for example, is used to locate brain tumors, measure cardiac output, and determine liver and thyroid activity. Rubidium-82 is used in cardiology diagnosis. Carbon-14, a radioisotope used to date organic materials as old as 50,000 years, is also used to study abnormalities of metabolism that underlie diabetes, gout, anemia, and acromegaly. Aluminum-26 is used in biological studies into the causes of Alzheimers' disease and in material science experiments. Silicon-32, a by-product of the technology used to produce aluminum-26, is used to study nutrient metabolism in single-cell phytoplankton plant life—most notably the diatom, which is a type of algae that researchers believe plays a major role in influencing climate change. Studying the uptake of silicon in diatoms provides information needed to precisely model the effects of greenhouse gases on global climate.

In industry, radioisotopes of various kinds are used for measuring the thickness of metal or plastic sheets and to examine manufactured metal parts for structural defects. Also, heat produced in the decay of radioactive isotopes can be converted into electricity for use as compact sources of electrical power in, for example, cardiac pacemakers and spacecraft. Other important isotopes used in biomedical, industrial, environmental, fundamental physics, and material-science research and development include arsenic-73, beryllium-7, bismuth-207, cadmium-109, gadolinium-148, niobium-92, rubidium-83, selenium-72, technetium-95m, titanium-44, vanadium-48, vanadium-49, yttrium-88, zinc-65, and zirconium-88. A year-round, uninterrupted supply of these and many more important radioisotopes is now possible with the construction of the new Isotope Production Facility (IPF) at LANSCE.

New Target Irradiation Capability at LANSCE

The radioisotope program at Los Alamos National Laboratory (LANL) has been one of the more successful and visible ongoing endeavors in the production and distribution of isotopes nationwide. As an essential element of the nation's health care program, it depends on the Laboratory's ability to deliver key medical radioisotopes to customers on a year-round daily basis. LANSCE has supported the program by producing radioisotopes for more than twenty years. Without the production capabilities at LANSCE and other national and international facilities, DOE will not be able to meet the needs of its radioisotope customers. More than a billion dollars of installed and operational medical instruments that depend on these radioisotope supplies will be adversely impacted if these materials are not made available.

The production of radioisotopes at LANSCE traditionally took place when excess beam from the linac was used to irradiate targets located near the beam stop in experimental Area A. But a changing mission and new experimental program at LANSCE has led to facility and accelerator modifications whereby excess beam will no longer be available for radioisotope production in Area A. Meeting the continuing demand for radioisotopes from industry, research institutions, the medical community, academia, and government therefore necessitated the design and construction of a new IPF at LANSCE (Fig. 1). The completion and commissioning of this new target irradiation capability, at an estimated cost of $20 million, will ensure a dedicated year-round supply of radioisotopes when combined with similar isotope production capabilities at Brookhaven National Laboratory and supplemented by international collaborations with TRIUMF (Vancouver, Canada), Institute of Nuclear Research (Troitsk, Russia), National Accelerator Centre (Faurve, South Africa), and Paul Scherrer Institute (Villigen, Switzerland). The IPF project was first initiated in November 1998. In 1999, a detailed design of the facility and equipment was completed, and facility construction began in February 2000. The facility will become operational in 2003.



▲ ***Fig. 1.*** *Artistic rendering of the IPF.*

One essential goal remains at the forefront of this nationally and internationally important project—to provide a state-of-the-art facility that will continue the production of medical isotopes at LANL. The main systems of the new IPF will include upper- and lower-level building structures to house special IPF equipment, a new beam line that extends to the target irradiation area below ground (in the lower-level of the facility), and target equipment and a hot cell in the upper level of the facility to handle the irradiated targets. The scope of this project includes the design and construction of a beam-line tunnel and targeting area, the design and construction of an upper-level building to house mechanical and remote handling equipment, the design and construction of an accelerator beam line, the modification of one segment of the LANSCE accelerator, and the design and construction of target irradiation and remote handling systems.

When complete, the IPF will follow a normal operating sequence that begins with loading targets into the beam-stop area and ends with shipping irradiated targets to a processing facility where radioisotopes are separated from the irradiated targets and prepared for distribution.

Innovative Target Insertion and Retrieval Operations

The LANSCE accelerator is made up of three components—an injector that accelerates a proton beam to 750 KeV, a drift-tube linac (DTL) that further accelerates the beam to 100 MeV, and a side-coupled cavity linac (SCCL) that further accelerates the beam to 800 MeV. The region between the DTL and the SCCL provides a transition zone where a 100-MeV proton beam can be extracted from the existing main beam line (Fig. 1). A fraction of the

100-MeV proton (H^+) beam is extracted and then deflected 45° by a new kicker magnet and a direct-current bending magnet. The extracted beam is transported through a new beam line to a radioisotope production target chamber located in the IPF's lower level (underground). (The undeflected proton beam continues into the SCCL where it is accelerated to 800 MeV for use in other beam lines.) The new beam line ends at the target chamber where the beam passes through an exit window and irradiates the target assembly—a stack of flat metal plates arranged in a holder along a horizontal center line of the beam (Fig. 1 inset). Spaces between the plates are filled with flowing water coolant to prevent the targets from melting and to absorb some of the proton beam energy. The front plate in the target assembly experiences nearly the full 100-MeV beam energy, whereas plates further back in the stack will experience progressively lower beam energies. As the beam passes through the successive layers of plates and water, it slows to a stop in the last plate. The cross-sections for the nuclear reactions needed to produce useful radioisotopes have resonances in the 20- to 100-MeV range. As such, several production reactions can be initiated simultaneously with the appropriate target materials, thickness, and arrangement.

A remotely operated target transport mechanism inserts and retrieves targets through a vertical shaft between the target chamber in the lower level of the facility and a hot cell in the upper level. This mechanism guides the target assembly between the target chamber and the hot cell and ensures that targets are in proper placement for irradiation. The hot cell provides a shielded working area where radioactive targets are remotely mounted, unmounted, and loaded into shipping casks using manipulators and a shielded viewing port constructed of leaded glass. Fresh targets and other small objects are brought into the hot cell through a shielded sample feed-through mechanism. The hot cell is shielded on three sides and on the top with concrete and steel shielding. The fourth side consists of a shield door, which provides access to the interior of the hot cell when necessary. Certified casks are used to ship irradiated targets from the IPF to the chemical processing facility. An overhead monorail crane transfers the casks to and from a truck that is backed into the facility through a roll-up door.

Factors Affecting Radioisotope Production

When the proton beam impinges on the first plate of the target assembly, several things happen simultaneously. Some of the protons interact with the target nuclei to form the product nuclei. Take for example the irradiation of zinc metal or oxide to produce copper-67—an important radioisotope used in lung-cancer research and in monoclonal antibody labeling. (Monoclonal antibodies are pure, uniform, and highly sensitive protein molecules produced by genetic-engineering techniques for use in medicine to diagnose and combat a number of diseases.) Sufficiently energetic protons will react with zinc-68 nuclei in the target, resulting in the absorption of one proton and the emission of two others. This reaction results in the formation of copper-67 nuclei. The factors that determine the amount of copper-67 produced in this reaction include (1) the number of zinc-68 atoms placed in the beam, (2) the number of protons per unit time that strike the target, (3) the probability that a proton will actually collide effectively with a zinc-68 nucleus and give rise to the desired nuclear reaction, and (4) the duration of the bombardment. Maximizing all these factors produces the best yield of copper-67.

Protons that do not participate in the nuclear reactions are impacted in two important ways. First, the protons lose energy as they pass through the targets and the cooling water. Second, they are deflected from their incident path, resulting in a broadening of the beam. The new IPF will take advantage of the first phenomenon by configuring the target stack to give the desired energy range in one or more successive targets. Targets at the front of the stack will be used to degrade the beam energy to the desired levels for subsequent targets. (The beam energy range in a target is an important factor in maximizing the probability of the desired nuclear reaction.) In this way, several targets can be irradiated at different energies simultaneously, thus maximizing the efficiency of the facility.

The new IPF target assemblies will be thick enough so that the beam energy will be degraded to zero within the last target in the assembly. With all of the beam energy deposited into the target materials, the target assembly must be cooled (as described above) to keep the targets from melting. The cooling is accomplished by circulating cooling water between the target plates. The thickness of the water channels is important not only in achieving effective heat transfer but also in obtaining the desired amount of beam energy degradation for subsequent targets.

One consequence of the deflection of protons noted above is that even a narrowly mono-energetic beam will acquire an energy spread. The extent of this energy spread will depend on the nature of the incident particles, the nature of the target material,

and the physical thickness of the target. The FWHM (full-width at half-maximum) of the energy distribution is a measure of this energy straggling, and it increases with the depth of the beam in the target assembly. This beam energy spread may limit the control that can be exercised over nuclear-reaction channels in targets located at the back end (low energy) of the target stack.

Many factors must therefore be considered in relation to irradiating targets to yield useful quantities of radioisotopes. Beam energy, beam current, desired nuclear-reaction cross sections, undesired nuclear-reaction cross sections, target configuration, target mass, and stopping power are all critical parameters. Ultimately, production yields from specific target configurations are best determined empirically. The new IPF will provide an important research capability for determining such yields.

With the construction of the new target irradiation capability at LANSCE, LANL will continue its twenty-year-old tradition of producing and distributing a rich variety of radioisotopes for medical, industrial, environmental, and other tracer applications.

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